Identifying the Presence of Biosignatures on Exoplanets and Moons in our Solar System

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Abstract

Research Question: What can we deduce about the potential presence of biosignatures and habitability of moons in our solar system, and exoplanet atmospheres, based on a comparison of their spectra to Earth's spectra?

In this project, we compared spectral features of Jovian moons and exoplanets to those of Earth, with the goal of finding biosignatures in the spectra. By analyzing current data regarding known terrestrial atmospheric biosignatures to local moons, exomoons, and exoplanets, we determined the presence of water, and organic elements in the various spectra, within a 2.5 sigma uncertainty if the uncertainty data was available. Additionally, we investigated organic compounds in WASP-39b using Raman spectroscopic methods. Our results display qualitative correlations between known biosignature wavelength bands in the 0.4-1.8 micron range and encourage extended data analysis when future data becomes available.

Background

With rapidly advancing space technologies and instrumentation, researchers can study the atmospheric compositions of lunar and planetary systems using infrared spectroscopy. Spectroscopy is the study of the emission and absorption of light by matter. Spectral analysis is the process of analyzing a spectrum and characterizing the composition of the source of electromagnetic radiation, like this one. In our project, we focus on the infrared wavelength range due to its ability to pass through cosmic dust.

We choose water as our primary biosignature due its necessity in biological processes like photosynthesis, cellular respiration, as well as maintaining cellular structure in aerobic organisms. Additionally, water vapor has a strong near-infrared wavelength features that align with the ranges of wavelengths observed in available spectral datasets at 1.38 microns[2].

We determine the presence of water absorptions and reflectance bands at different wavelengths in the spectra of exoplanets WASP-39b and KELT-11b and the Galilean satellites Europa, Callisto, and Enceladus. We also present an application of carotenoids, an organic biosignature, as a qualifier for whether an exoplanet can sustain terrestrial life[3].

Methodology

Our goal was to obtain spectral data (preferably infrared) of exoplanet atmospheres, earth's atmosphere, moons in our solar system, and the properties of water. We found the most abundant data from planet Wasp 39-B From the NASA Exoplanet Archive. Data on Europa, Enceladus, and Callisto was collected from various sources including a research paper and data from Courtney Dressing's Astron 7A class. We also later found data on exoplanet Kelt-11B which was found from an article published by the American Astronomical Society. Once we had extracted data from notable research papers and data archives, we performed spectral analysis by aligning the spectral features of biosignatures with the spectra of the celestial bodies we are studying. We plotted visualizations of our spectra to qualitatively and quantitatively compare the spectral data that we have collected with different known wavelength bands of elements and Earth's spectra.

Figure 1

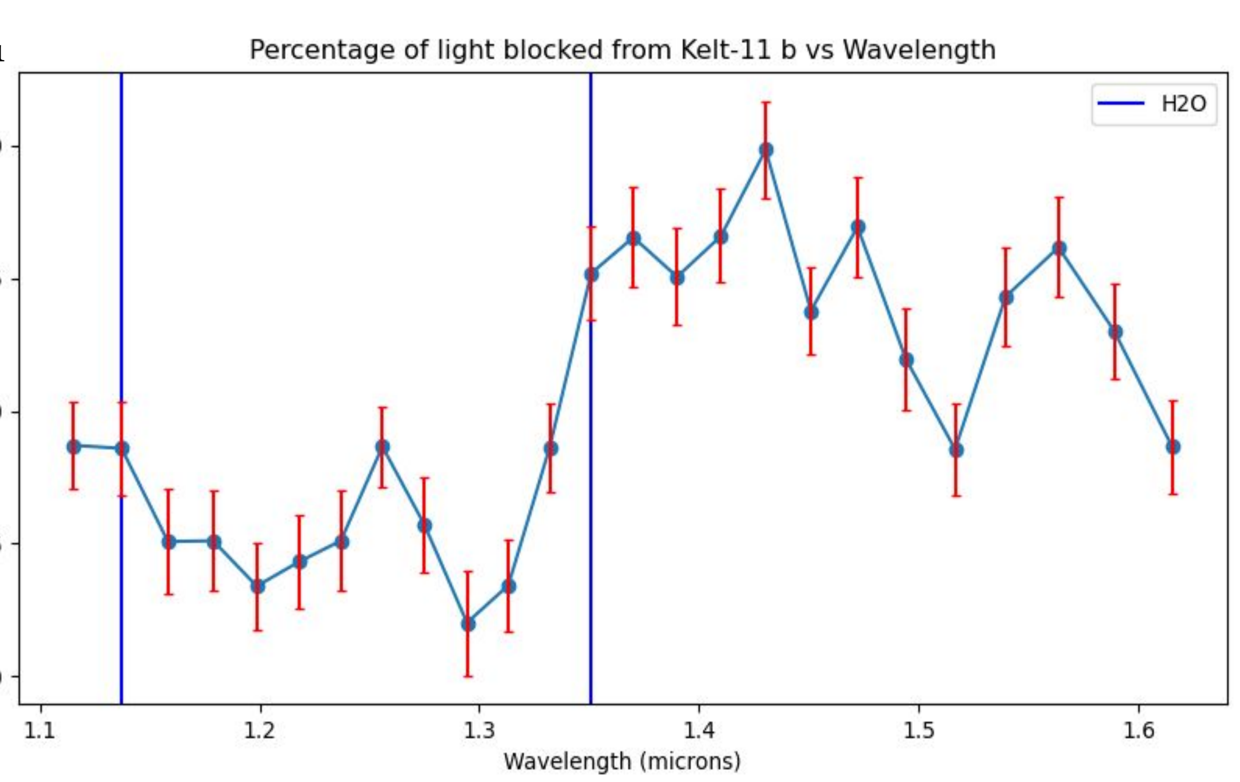

Figure 1 is the transmission spectra of a hot-Jupiter exoplanet called KELT-11 b. This transmission spectra data is gathered from HST WFC3 from a single transit in the near infrared. Even though the planet is a hot-Jupiter and not a terrestrial planet like Earth it still has valuable spectra data for the formation of the planetary system. There are 2 indicators for water absorption lines at 1.1372 and 1.3509 microns. Moreover this figure is a basis idea of our goals for plotting spectral data, discovering biosignatures on exoplanets such as water, and we later found a lot more spectral data on another exoplanet called WASP-39 b.[6]

Figure 2

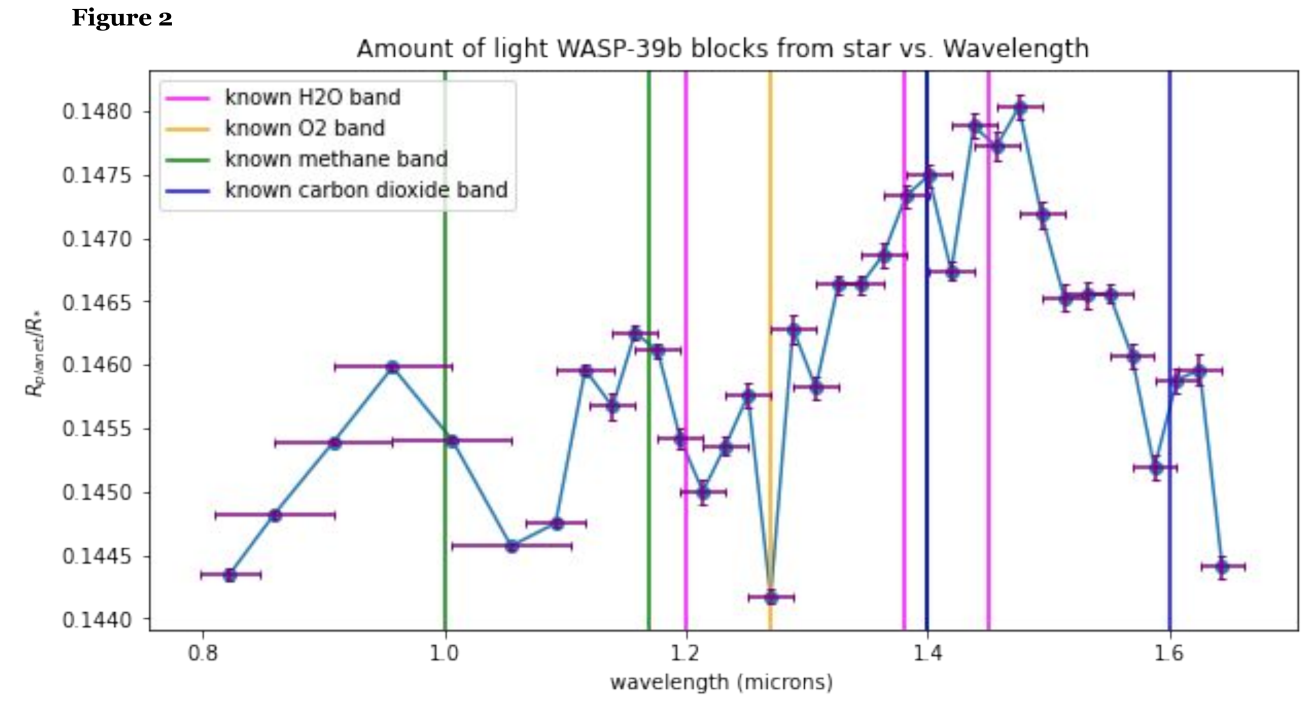

Figure 2 displays the absorption bands present from the exoplanet WASP-39b[4]. Although we are primarily looking for water vapor features, several other atmospheric biosignatures such as dioxide, methane, and carbon dioxide are plotted. The water absorption band values we looked at were 1.2, 1.38, 1.4, and 1.45 microns[9]. The absorption band corresponding to water at 1.2 microns has an uncertainty of 1 sigma for the wavelength value at 1.2699 microns. Additionally, stronger absorption bands corresponding to water at 1.38 microns and 1.42 microns have uncertainties of 2 and 1.5 sigmas, respectively, of the actual wavelength data point at 1.3674 microns. However, there is an absorption band corresponding to both water and carbon dioxide at 1.4 microns that lies within an uncertainty of 1 sigma of this data point. We also matched an absorption band that corresponds to dioxide at 1.25 microns.

Figure 3

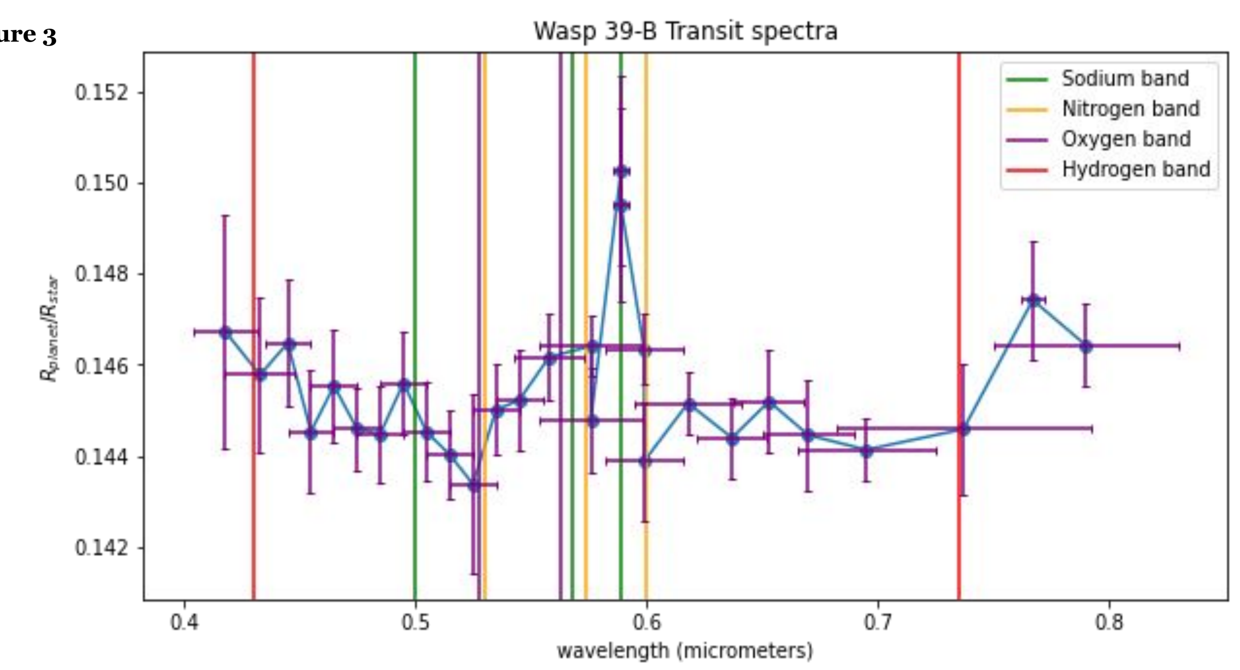

Figure 3 shows the spectral data of exoplanet WASP-39b, found from the NASA exoplanet archive.[5] The plotted over lines on the spectra are approximated wavelength bands of four different elements- Sodium, Nitrogen, Hydrogen, and Oxygen- present in the transmission spectra of an Earth-like atmosphere. The behavior of these elements in the transmission spectra of an earth-like planet can be seen on the comparison image below.[4] There is a nitrogen band centered at approximately .6 um which lines up with the dip in the graph at .6um. A sodium band of .589um also falls within 1 uncertainty of that dip. Another nitrogen band is centered at approximately .574 um which is well within 1 uncertainty of the dip at .576um. Additionally, there is an oxygen band centered at .5275um within one uncertainty of the dip at .525um.

Figure 4a **Figure 4b**

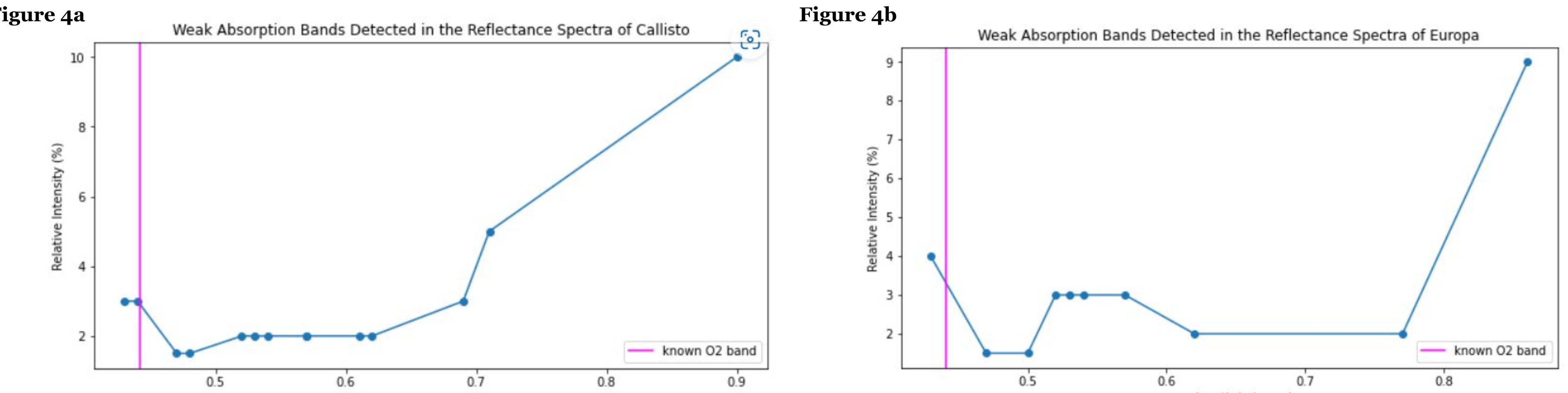

Figure 4: The figures display the relative wavelength intensities of certain wavelengths of two Galilean satellites, Callisto and Europa and a known O2 band. The graph displays the ratio of reflected energy to incident radiation as a function of the wavelength which in turn correlate to elements. Each data point represents the relative intensity of each wavelength absorbance. A known O2 band was identified at 0.4414 microns and plotted in magenta on both graphs. While the Europa data (Figure 4b) does not have any aligned data points with this band, the Callisto data set (Figure 4a) does have a point in which the O2 band intersects. This is significant because it shows the possibility of O2 from a water ice host material. However, it is important to note that the sample size for this data set is not substantial. The last Galilean missions that regarded these moons were in the 1980s and 90s; therefore, much of the data was on outdated platforms that we were unable to access.

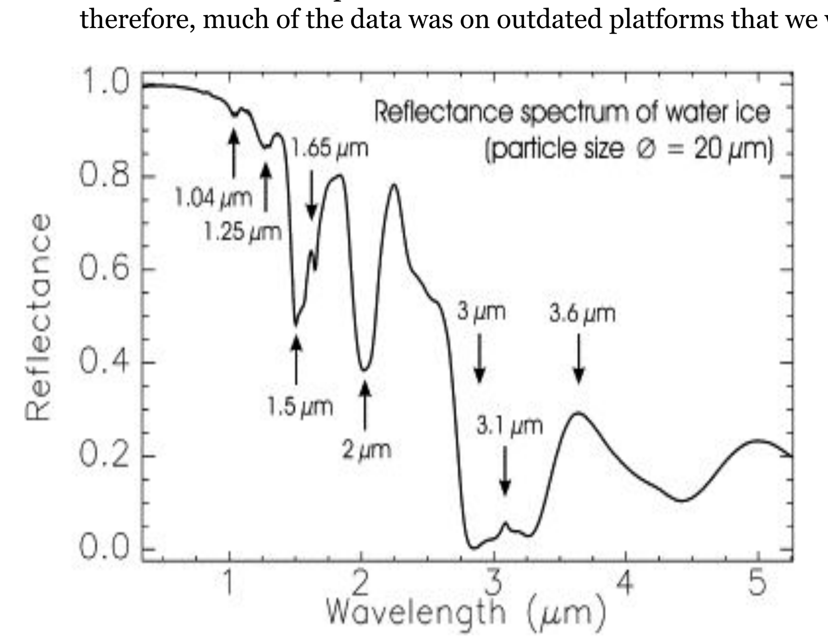

Figure 5 plots transmission spectra taken from JWST done in an Astrophysics 7a lab. The transmission spectra both includes model spectra with Co2 and without.The several transmission peaks correlate with transmission spectra where Co2 was detected in the atmosphere of WASP-39b. While JWST measures from the 3.0-5.0 μm range the absorption features were least prominent in the 4.0-4.5 μm.

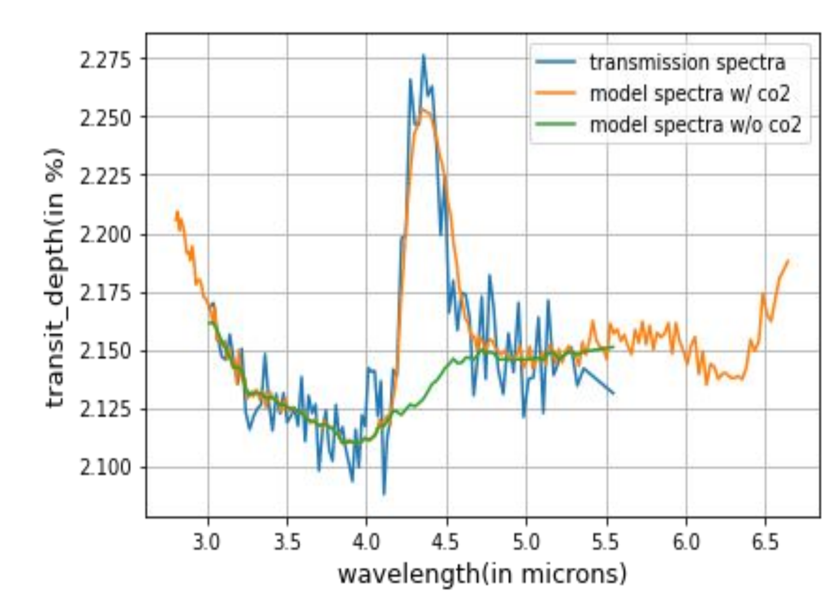

Figure 6 shows compiled data taken from the 3 Cassini flybys in 2005. It shows the main peaks of crystalline water ice from Enceladus with absorption bands at 1.04, 1.25, 1.5, 1.65, 2.0 μm, with several absorption features in the 3 μm range using VIMS.(The Visual and Infrared Mapping Spectrometer).VIMS data range was set to 0.35 to 5.2 μm. The variations of the band depths are primarily caused by the variations in particle size. A wavelength range between 1-5 μm corresponded to an uncertainty data of 50% below the measured band depth variances of a factor 4 and greater.

Figure 7

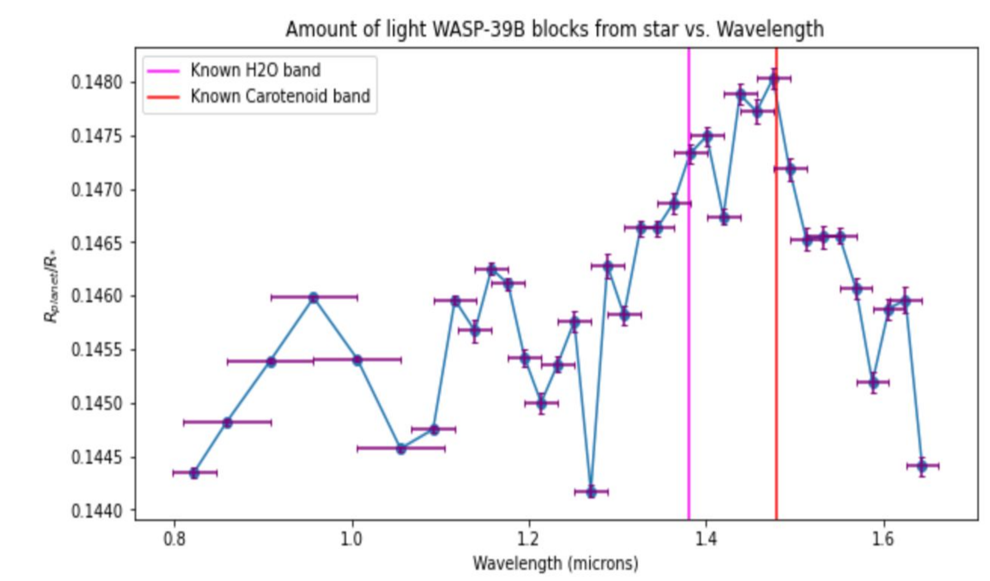

Figure 7 is the spectral data set[4] obtained from WASP-39b utilized in Figure 2. Here, we plotted the two strongest bands for carotenoids using Raman spectroscopy at 1.48 microns for spectral analysis. The 1.48 band falls within a 2.5 sigma uncertainty on the graph.

Conclusion

We determined the potential presence of biosignatures such as water, carbon dioxide, dioxide, methane, nitrogen, sodium, oxygen, and carbon in the various spectral data within 2.5 sigma uncertainties that we collected from exoplanets and moons. More importantly, we found different states of water at different wavelength bands in the infrared in all of our spectra. Such findings characterize these environments as potentially habitable due to the presence of such biosignatures, especially water vapour and carbon dioxide.

One limitation we encountered in our research was restricted sizes of datasets as well as restricted access to raw data, such as extracting data from a spectral cube mission. Additionally, all the exoplanets we found were hot Jupiters, so it was difficult to find raw data on planets that could be considered habitable. Thus, we were not able to determine habitability for life as we know it of the exoplanets we studied. However, as exoplanet science and instrumentation advances, the methods of spectral analysis that currently exist for hot Jupiters can be extended to terrestrial planets to investigate habitability, or even determine the present of life. Spectral analysis can also help determine the composition of planets, planet formation, and planetary systems.

Future Work

This project heavily focused on investigating biosignatures at the infrared wavelength band, the wavelength bands that the James Webb Space Telescope (JWST) is capable of obtaining data in, which intends to conduct a massive intergalactic survey of extraterrestrial objects. We offer qualitative guidelines for determining habitability of said objects that JWST and other future surveys may utilize and emphasize candidate objects for further investigation. Future work should aim to conduct data analyses of uncertainties once available to determine percentage errors in the identification of biosignatures in spectra.

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